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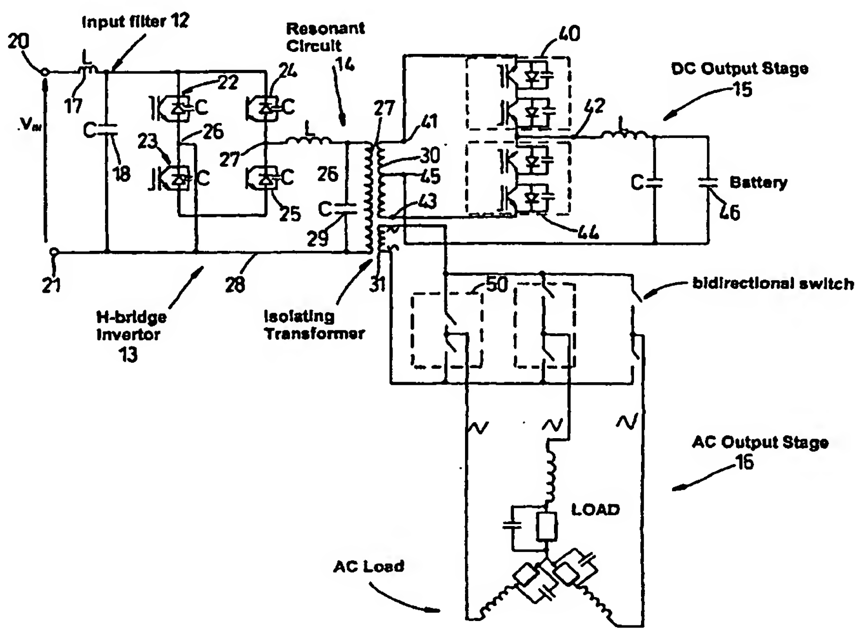

(57) Abstract

A heavy duty isolating converter adapted to convert a nominally DC input voltage into a regulated output voltage is disclosed. The converter comprises an input circuit (10) coupled to the primary side (27) of an isolating transformer adapted to produce a voltage signal in the transformer; and an output circuit (15, 16) coupled to the secondary side (30, 31) of the isolating transformer adapted to produce a regulated voltage from the voltage signal in the transformer. The input circuit (10) comprises a switching circuit (22, 23, 24, 25) adapted to convert a voltage signal present across a first and second input node into a pulse width modulated signal across a first and second output node by selectively connecting the voltage present across the first and second input nodes to the first and second output nodes in alternating directions at a first switching frequency, and a resonant circuit (14) is adapted to receive a signal dependent upon the voltage applied across the first and second output nodes of the switching circuit and generate a sinusoidal voltage signal adapted to be applied across the primary side of the transformer. The resonant frequency of the resonant circuit corresponds substantially to the switching frequency of the switching circuit and the amplitude of the sinusoidal signal applied across the transformer is dependent upon the amount of energy supplied to the resonant circuit stage by the switching circuit.

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IMPROVED HEAVY DUTY ISOLATING CONVERTER

This invention relates to improvements in heavy duty electrical isolating converters of the kind adapted to convert a DC input voltage into an output suitable, for example, for driving auxiliary equipment in a car or vehicle and/or charging a battery. In particular, it relates to converters adapted to generate both a multi-phase alternating output voltage and a DC output voltage.

Converters of the kind set forth are widely used in the power supply system for railway carriages, electrical multiple units, locomotives, trolley buses and trams. In such applications, the input voltage comprises a supply line voltage which is subject to transients. This typically ranges from 500 to 1000 volts (750 volts nominal) up to 4000 volts nominal. A three phase output is typically required to drive electrical equipment at standard industrial voltages up to 480 volts RMS and 50-60 Hz, and the DC output is nominally required to be up to 130 volts and used for DC equipment. Of course, these values are largely dependent upon the application and the regional standard industrial and domestic voltages in various parts of the world.

Converters for these ranges are typically referred to as auxiliary converters, inverters, static inverters or auxiliary power supplies.

A typical prior art converter is shown in block schematic layout in Figure 1. The converter comprises an input stage 1 and an output stage 2 connected by an isolating transformer 3. The input stage is adapted to produce a substantially square wave pulse width modulated signal which is fed to the transformer primary. This signal is then fed from the secondary side of the

transformer to a bridge rectifier which produces a DC intermediate signal. Finally, this signal is converted to AC and/or DC as required.

The presence of the square waveform in the transformer and the need to convert this waveform into DC is often referred to in the art as a DC link. It presents several problems to the designer, the main one being the problem of EM interference due to radiation generated in the transformer core as the square wave contains large amounts of high frequency components.

In accordance with a first aspect, the invention provides a heavy duty isolating converter adapted to convert a nominally DC input voltage into a regulated output voltage comprising an input circuit coupled to the primary side of an isolating transformer adapted to produce a voltage signal in the transformer, and an output circuit coupled to the secondary side of the isolating transformer adapted to produce a regulated voltage from the voltage signal in the transformer, in which the input circuit comprises a switching circuit adapted to convert a voltage signal present across a first and second input node into a pulse width modulated signal across a first and second output node by selectively connecting the voltage present across the first and second input nodes to the first and second output nodes in alternating directions at a first switching frequency, and a resonant circuit adapted to receive a signal dependant upon the voltage applied across the first and second output nodes of the switching circuit and generate a sinusoidal voltage signal adapted to be applied across the primary side of the transformer, the resonant frequency of the resonant circuit corresponding substantially to the switching frequency of the switching circuit and the amplitude of the sinusoidal signal applied across the transformer being dependent upon the amount of energy supplied to the resonant circuit stage by the switching circuit.

The invention thus eliminates the hard switched square wave signals in the transformer in the prior art by providing a resonant circuit between a switching stage and the primary transformer winding, the resonant circuit producing a sinusoidal output at its resonant frequency of amplitude corresponding to the amount of energy supplied by the switching circuit.

The switching circuit may be adapted to vary the mark-space ratio of the pulse width modulated signal fed to the resonant circuit by varying the ratio of the time in which the voltage across its first and second input nodes is connected in one direction across the input nodes of the resonant stage to the time it is connected in the opposite direction within each duty cycle. Most preferably, the mark-space ratio is decreased as the line voltage applied to the converter is increased so that the total energy supplied to the resonant stage remains substantially constant. By changing the switching patterns, the peak voltage across the primary side of the transformer can be kept constant independent of the input line voltage if desired.

An input filter circuit may be provided between the lines carrying the input line voltage and the first and second nodes of the switching circuit. The filter circuit may be adapted to minimise the effect of transients in the line voltage from being fed to the switching stage. The filter may also be adapted to prevent the converter providing an unacceptable load on the line voltage supply.

The switching circuit may comprise a four arm bridge, each arm comprising a switching assembly. A first pair of switching assemblies may be connected in series between the first and second input nodes of the switching circuit, and the second pair of switching assemblies may also be connected in series between the first and second nodes. The two pairs of switching assemblies may therefore be connected in parallel with one

another. A centre tap between the first pair of switching assemblies and a centre tap between the second pair of switching assemblies may define the first and second output nodes which provide the take-off point for feeding a voltage signal to the resonant circuit stage.

A first control circuit may be provided which is adapted to control the operation of the switching assemblies. Each switching assembly may comprise at least one semiconductor device which is switched between a non-conducting state and a conducting state by applying a control voltage to the device. An anti-parallel diode may be connected across each switching device. The switching assemblies may be controlled using a soft switching strategy.

The switching frequency of the switching circuit may be chosen to be around 30 kHz. However, other lower frequencies may be selected, from around 2 kHz upwards, and higher frequencies may also be selected, up to 50 kHz or more. The resonant frequency of the resonant circuit may be selected to match this switching frequency.

Each switching device may comprise an IGBT (Isolated Gate Bipolar Transistor) although other suitable devices are envisaged.

The resonant circuit may comprise a series resonant LC circuit. The capacitor may be connected in parallel across the ends of the primary transformer winding. When excited at the resonant frequency (or close to that frequency), the voltage across the resonant capacitor is magnified. The amount of magnification depends on the Q factor of the circuit. The circuit may have a low Q. A Q of between 1.5 and 2.5 is preferred, although other values can be selected.

The use of a capacitor in the resonant circuit acts as a store of energy which provides a degree of ride-through capability which can make if possible to reduce the energy storage requirements of the input waveform in the transformer.

The use of a parallel loaded LC circuit is also advantageous in inherently limiting short-circuit currents because of the impedance of the resonant inductance.

The output circuit may comprise at least two subcircuits, which may be independent in operation.

A first output subcircuit may comprise an AC-AC converter adapted to produce a three-phase output voltage from the sinusoidal voltage induced in a secondary winding of the transformer by the sinusoidal voltage supplied to the primary winding by the resonant circuit.

The second subcircuit may comprise an AC-DC converter adapted to produce a DC output voltage from the sinusoidal signal in a secondary winding of the transformer produced by the sinusoidal signal in the primary winding.

Each of the subcircuits may be connected to a separate winding of the transformer. The first subcircuit may be connected between the ends of a secondary winding, whereas the second subcircuit may be connected across both ends of a secondary winding and also to a centre tap of the winding. The centre tap may be earthed.

The three-phase AC-AC converter subcircuit may comprise a switching circuit connected between the secondary winding and three AC output

nodes. The output frequency of the substantially sinusoidal alternating voltage produced by the three-phase AC-AC converter at the output nodes is preferably lower than the frequency of the sinusoidal voltage in the secondary winding. An AC output voltage at 50 Hz or 60 Hz is preferred, although any number of desired frequencies could be produced. Thus, the frequency of the AC output may be about one, two or three orders of magnitude lower than the frequency of the sinusoidal waveform in the transformer windings.

The three-phase AC-AC converter may comprise three conducting arms. Each arm may comprise a first and second bi-directional switching assembly connected in series between the ends of the transformer winding, the three arms being connected in parallel. A respective phase of the AC three phase output voltage may be obtained by taking a centre tap from between the first and second bi-directional switching assemblies in a respective arm. The centre tap point may therefore define an AC output node.

Each switching assembly may comprise a pair of transistors or other semiconductor devices (BJT'S, IGBT'S, IGFET'S) connected in reverse, i.e. collector to collector or emitter to emitter for the case of BJT, IGBT. A diode may be connected in anti-parallel across a respective switching device, for example between a collector and emitter. A small RC snubber network may also be connected across one or more of the devices to control diode recovery.

Each pair of switching assemblies may be adapted to allow current to flow in one direction only through the arm when one device of the pair is on whilst the corresponding device is off, and allow current to flow in the

opposite direction only through the arm when the state of the two devices is reversed.

A second control circuit may be provided which is adapted to control the operation of the switching devices in the first output subcircuit. This may be integral with the control unit for the input stage switching circuit. The devices may be controlled using a soft switching strategy.

The control circuit may switch the switching devices in one arm so that the voltage present at the respective centre tap is modulated over time to approximate (when smoothed) a sinusoidal waveform corresponding to the desired AC waveform. This modulation may be performed in a similar manner for each of the three arms to provide three substantially identical waveforms separated by 120° of phase shift. Since an AC sinusoidal output comprises four similar sections of 90 degrees, the control sequence for constructing only one section need be calculated/stored. This can then be used to replicate the remaining three sections.

The second subcircuit, the DC output stage, may comprise at least four switching devices connected in a bridge, switching of the devices being adapted to rectify the sinusoidal waveform in the associated secondary winding to produce a substantially single polarity output.

A filter circuit may be provided to smooth the rectified output of the DC output stage. A battery may be connected across the output to act as a store of charge for use as a back-up supply.

A third control circuit may be provided for controlling the switching devices of the DC output stage. This may be integral with the first and/or second control circuits.

The control circuit may include a microprocessor unit and a digital to analogue converter.

The converter is preferably a high power device adapted to convert line voltages in the order of 450 volts nominal to 4000 volts nominal.

In accordance with a second aspect of the invention, an auxiliary power supply for a carriage or vehicle comprises a converter according to the first aspect, input terminals for connecting the converter input to a line voltage, and output terminals across which the output from the converter may be accessed.

The auxiliary power supply may further include a battery adapted to store charge.

In accordance with a yet further aspect of the invention, a carriage or vehicle includes an auxiliary power supply according to the second aspect of the invention.

An embodiment of the invention is shown in the accompanying drawings by way of example in which like numerals indicate like elements (or groups of elements) and:

Figure 1 illustrates a prior art converter for use on a carriage or vehicle;

Figure 2 is a schematic block diagram illustrating one embodiment of the present invention;

Figure 3 is a simple circuit diagram of a converter illustrated in figure 2

Figure 4 is a circuit illustrating the bi-directional switch assemblies;

Figure 5 is a simplified circuit corresponding to the resonant input stage fed by a square or rectangular wave Vs; and

Figure 6 shows a typical output waveform generated in the AC-AC output stage.

The converter is schematically in Figure 2 of the drawings. A circuit diagram is shown in Figure 3. The converter comprises a primary side circuit 10 (all those components to the left of the transformer including the primary side transformer winding, and a secondary side circuit 11 (all those remaining components). The primary side circuit can be considered to be further subdivided into three substages.

Stage A: Input filter 12 which removes line transients and ensures that electrical converter circuit does not affect supply line, connected to;

Stage B: Switching circuit 13 which converts the filtered line voltage into a pulse width modulated signal of fixed frequency, and which is passed to; and

Stage C: A resonant filter circuit 14 which resonates at the switching frequency of the switching circuit, the amplitude of the resonant sinusoidal output being dependent upon the amount of energy supplied by the switching circuit stage B.

The secondary side circuit can be considered to comprise two subcircuits:

Stage D: an AC to DC converter 15 which generates a DC supply for charging a back-up battery; and

Stage E: an AC to AC converter 16 which produces a three-phase AC output voltage.

The operation of the individual circuit stages, and their combined integration in the complete circuit is described hereinafter.

The converter is designed to convert a line voltage Vin, for example from an overhead line or third rail in a railway or tram system into both an AC supply for driving auxiliary equipment in a car such as lighting and air-conditioning, and a DC voltage for supplying DC controls and charging a back-up battery which can be used in the event of line voltage failure.

The line voltage depends to a large extent upon the particular application of the circuit, and the design can be tailored to operate from different line voltages by either altering component values or by varying the switching control operation of the switching circuits.

The input filter 12 provided across the input terminals 20, 21 comprises, in its simplest form, an inductor 17 and a capacitor 18, the capacitor being connected across the two input terminals and the inductor 17 being provided in series between one end of the capacitor 18 and one of the input terminals.

The output from the input filter stage 12 is then fed to an H-bridge converter 13. The inverter 13 comprises four switching assemblies 22, 23, 24, 25. The switching assemblies are movable between an open and closed position. The assemblies are divided into pairs 22, 23 and 24, 25. Each pair comprises two assemblies connected in series and the

two pairs are connected in parallel across the output of the filter stage. The output of the switching circuit is obtained by taking taped outputs or nodes 26, 27 from between each of the switching assemblies of a pair.

By switching the switching assemblies between the open and closed position, it is possible to force the voltage across the two output nodes 26, 27 between a positive value (in which current flows one way through the bridge), a negative value or a zero value (in which current flows in the opposite direction through the bridge). This switching is performed at a constant frequency to produce a pulse width modulated output voltage across the two taped outputs. The mark-space ratio of the pulse width modulated output is selected so that a constant amount of energy is supplied to the output nodes regardless of line voltage. For this purpose monitoring means for measuring the line voltage, or the voltage present at some other point in the converter circuit may be provided.

In the arrangement illustrated, the mark-space ratio of the pulse width modulated signal is chosen to provide a square wave output at minimum expected line voltage. At higher line voltages, the mark-space ratio decreases. The effect of this control is to supply a constant amount of energy to the following resonant circuit stage.

The pulse width modulated signal is fed onto the inputs of a resonant circuit 14. In the embodiment shown, this comprises an elementary L-C circuit comprising a series inductor 36 connected between one tap of the bridge and one side of the primary winding 37 of a transformer, a conducting link 28 connecting the other tap to the opposite end of the primary winding and a capacitor 29 connecting the ends of the primary winding.

A simplified representation of the resonant circuit is shown in figure 5. Vs represents the rectangular PWM signal fed from the switching circuit. The transformer is shown as having a turns ratio of N:1.

The transfer function between the input terminals and the voltage across the primary winding of the transformer becomes

$$\frac{Vo}{Vin} = \frac{R.N^2}{s^2.LCRN^2 + sL + RN^2}$$

where Vin=Vs and s is the laplace operator. When force driven at the resonant frequency ω_O, 's' can be substituted by "$j\omega_O$".

The inductance and capacitance can be described in terms of the load, the required circuit Q and the resonant frequency.

The frequency is constant and the load is defined in terms of the system rating and, as noted above, the Q can be defined in terms of the turns ratio. This gives the following series of expressions:

$$Q(V_S, e_{OP}, N) := j \cdot K_V(V_S, e_{OP}) \cdot N$$

$$L(V_S, e_{OP}, N, VA) := \frac{R_{OS}[VA] \cdot N}{K_V(V_S, e_{OP}) \cdot \omega_0}$$

$$C(V_S, e_{OP}, N, VA) := \frac{K_V(V_S, e_{OP})}{R_{OS}(VA) \cdot N \cdot \omega_0}$$

The expression for the magnitude of the current circulating in the resonant circuit can be taken as that across the resonant inductor (Vo - Vi)/sL. This resolves to the following expression

$$I_P(V_S, e_{OP}, N, VA) := \frac{\left[\left(1 - j \cdot K_V(V_S, e_{OP}) \cdot N\right) \cdot V_{in}(V_S, e_{OP})\right]}{j \cdot \omega_0 \cdot L(V_S, e_{OP}, N, VA)}$$

The following values can be used in a realisable circuit: Q=2, Turns ratio =1, resonant induction $L_P = 10 \times 10^{-6}$H, Capacitor = 2.6×10^{-6}F, transformer leakage inductance = 3×10^{-6}H for a resonant frequency of 30kHz,

The resonant frequency of the resonant circuit 14 is selected to correspond to the period of the pulse width modulated signal i.e. the switching frequency of the switching circuit. In this case, a frequency of about 30 kHz is chosen. This frequency allows a relatively small transformer to be selected. The voltage across the output nodes thus switches between positive, negative and back to positive once every 1/30,000 seconds (33.33 µseconds).

As the resonant frequency circuit is pumped by the pulse width modulated signal from the inverter, an approximately sinusoidal waveform at the resonant frequency is generated in the transformer primary winding. The amplitude of the sinusoidal wave is dependent upon the energy applied to the resonant circuit, which in turn depends on the mark-space ratio of the pulse width modulated signal and the line voltage. Because the frequency of the AC signal is linked to the resonant frequency of the resonant circuit, a sinusoidal waveform can be produced as the resonant LC circuit acts as a low pass filter. This contains fewer high frequency components than a square wave of equivalent frequency, and so reduces electromagnetic interference generated by the transformer.

The sinusoidal waveform in the primary winding 27 of the transformer induces a corresponding sinusoidal waveform in the secondary windings 30, 31 transformer. In this case, two secondary windings are provided, one of which 30 is provided with a centre tap which can be connected to a virtual earth. The transformer provides electrical isolation between the input circuitry and the output circuitry, ensuring that a direct connection cannot be made between the line voltage and the output of the converter in the event of failure of arms of the switches or wound components such as inductors. Of course, one secondary winding or three or windings could be provided.

The centre taped secondary coil 30 provides three input terminals for an AC-DC converter 15. The converter produces a smooth DC voltage from the 30 kHz sinusoidal voltage in the secondary coils using two bi-directional switches.

The AC-DC converter comprises a first bi-directional switching assembly 40 connected between one end 41 of the centre taped winding and a DC output node 42, a second bi-directional switching assembly 44 connected between the other end 43 of the centre taped winding and the DC output node 42, a first link between the DC output node and one side of a battery (or other load), and a second link between the centre tap 45 and the other end of the battery 46 to be charged (or other load).

Each bi-directional switching assembly 40, 44 comprises a pair of series connected switching devices adapted to move between an open and a closed position and vice versa. A reverse parallel connected diode is provided across each switching device.

In use, control means (not shown) open and close the two directional switches to force the voltage at the DC output node to a positive value relative to the centre tap voltage. Thus, the circuit acts as a half-wave rectifier. DC output voltage regulation is achieved by selective rectification of the secondary voltage. Of course, the voltage at the DC output node could be forced to a negative value if desired.

A smoothing filter provided in the link between the DC output node and the battery smoothes the rectified output voltage.

The other secondary winding supplies an approximately sinusoidal 30 kHz signal to an AC-AC converter 16 which produces a 3-phase alternating voltage suitable for powering auxiliary devices such as lighting or air-conditioning for a carriage or vehicle.

The AC-AC converter comprises three pairs 50, 51, 52 of bi-directional switches. The two switches of each pair of switches are connected in series between the ends of the winding, the three pairs being connected in parallel. A centre tap from each pair provides the take off point for each of the three phases respectively. As each pair works in a substantially identical manner for each of the three phases (other than a 120° phase difference between the voltage present at each take off) only the first pair is described in detail.

Each of the bi-directional switches assemblies comprises a pair of semiconductor switches connected to allow current to flow in one direction through the switches only. This direction can be varied by changing the setting of the switches under control of a control means.

A typical arrangement is shown in figure 4. Each bi-directional switch assembly comprises two series connected transistors 100, 101 connected

back to back. A diode 102, 103 is connected in reverse parallel across a respective transistor 100, 101.

When one transistor 100 is switched on (allowing current to flow from collector to emitter) and the other transistor 101 is switched off, current can flow in one direction only through the energised switch and the diode associated with the other transistor.

When the energisation of the switches is reversed, current can only flow in the other direction. Thus, by energising the switches, the current can flow only in one pre-selected direction.

By controlling the energisation of all the four switches in each arm of the inverter, it is possible to approximate a sinusoidal output waveform of low frequency from the 30 kHz wave in the transformer coil. In effect, the switches rectify the waveform to provide a positive or zero at the take off point when the positive half of a sinusoid is to be constructed, and a negative or zero value when the negative half of the sine wave is to be constructed. An illustrated waveform is shown in figure 6(a) before filtering and in figure 6(b) after filtering.

Of course, simple rectification as described above would produce only a rough approximation of a sine wave. However, by eliminating some of the cycles of the sinusoidal waveform by pulse width modulation of the control of the switches in the inverter, a pseudo-sine wave can be produced for each output phase. This can subsequently be filtered to smooth out any ripple present. This unsmoothed signal is shown in figure 5. Of course, this represents only one example of a possible synthesised "sinusoidal" signal.

It will be understood from the above description that the invention achieves the conversion of a DC input voltage into a DC output supply voltage and a three phase AC output supply voltage using solid state switches. Each switch must be operated by applying a control signal to the base. A micro-processor unit can be used to generate these signals to provide the correct switching sequences.

Whilst the control software has not been described, the production of suitable control software or hardware algorithms is within the scope of routine work of a man skilled in the art, and that the disclosure of a suitable routine is not necessary to enable the skilled man to perform the invention.

Furthermore, it will be understood that the circuit diagrams provided are only schematic, showing the operation of the various stages in their simplest form. Other arrangement of the various circuit elements are envisaged. For example, other filter circuits could by employed within the scope of the invention which do not use a single inductor-capacitor arrangement.

CLAIMS

1. A heavy duty isolating converter adapted to convert a nominally DC input voltage into a regulated output voltage comprising an input circuit coupled to the primary side of an isolating transformer adapted to produce a voltage signal in the transformer; and an output circuit coupled to the secondary side of the isolating transformer adapted to produce a regulated voltage from the voltage signal in the transformer, in which the input circuit comprises a switching circuit adapted to convert a voltage signal present across a first and second input node into a pulse width modulated signal across a first and second output node by selectively connecting the voltage present across the first and second input nodes to the first and second output nodes in alternating directions at a first switching frequency, and a resonant circuit adapted to receive a signal dependant upon the voltage applied across the first and second output nodes of the switching circuit and generate a sinusoidal voltage signal adapted to be applied across the primary side of the transformer, the resonant frequency of the resonant circuit corresponding substantially to the switching frequency of the switching circuit and the amplitude of the sinusoidal signal applied across the transformer being dependent upon the amount of energy supplied to the resonant circuit stage by the switching circuit.

2. A heavy duty isolating converter according to claim 1 in which the switching circuit is adapted to vary the mark-space ratio of the pulse width modulated signal fed to the resonant circuit by varying the ratio of the time in which the voltage across its first and second input nodes is connected in one direction across the input of the resonant stage to the time it is connected in the opposite direction within each duty cycle.

3. A heavy duty isolating converter according to claim 2 in which the mark-space ratio is decreased as the input voltage applied to the converter is increased so that the total energy supplied to the resonant stage remains substantially constant.

4. A heavy duty isolating converter according to any preceding claim in which an input filter circuit is provided between the lines carrying the input line voltage and the first and second nodes of the switching circuit.

5. A heavy duty isolating converter according to any preceding claim in which the switching circuit comprises a four arm bridge, each arm comprising a switching assembly, a first pair of switching assemblies being connected in series between the first and second input nodes of the switching circuit, and the second pair of switching assemblies also being connected in series between the first and second nodes so that two pairs of switching assemblies are connected in parallel with one another, a centre tap between the first pair of switching assemblies and a centre tap between the second pair of switching assemblies defining the first and second output nodes.

6. A heavy duty isolating converter according to claim 5 in which a first control unit is provided which is adapted to control the operation of the switching assemblies.

7. A heavy duty isolating converter according to claim 5 or claim 6 in which the switching assemblies are controlled using a soft switching strategy.

8. A heavy duty isolating converter according to claim 5 or claim 6 in which each switching assembly comprises at least one semiconductor device

which is switched between a non-conducting state and a conducting state by applying a control voltage to the device.

9. A heavy duty isolating converter according to claim 8 in which an anti-parallel diode is connected across each switching device.

10. A heavy duty isolating converter according to claim 8 or claim 9 in which each semiconductor device comprises an IGBT (Isolated Gate Bipolar Transistor).

11. A heavy duty isolating converter according to any preceding claim in which the switching frequency of the switching circuit is chosen to be around 30 kHz.

12. A heavy duty isolating converter according to any preceding claim in which the resonant circuit comprises a series resonant LC circuit.

13. A heavy duty isolating converter according to claim 12 in which the LC circuit has a Q of between 1.5 and 2.5.

14. A heavy duty isolating converter according to any preceding claim in which the output circuit comprises at least two subcircuits which are independent in operation.

15. A heavy duty isolating converter according to claim 14 in which a first output subcircuit comprises a multi-phase converter adapted to produce a three-phase output voltage from the sinusoidal voltage induced in a secondary winding of the transformer by the sinusoidal voltage supplied to the primary winding by the resonant circuit.

16. A heavy duty isolating converter according to claim 14 or claim 15 in which a second subcircuit comprises an AC-DC converter adapted to produce a DC output voltage from the sinusoidal signal in a secondary winding of the transformer produced by the sinusoidal signal in the primary winding.

17. A heavy duty isolating converter according to any one of claims 14 to 16 in which each of the subcircuits is connected to a separate winding of the transformer.

18. A heavy duty isolating converter according to claim 15 in which the multi-phase converter subcircuit comprises a switching circuit connected between the secondary winding and three AC output nodes.

19. A heavy duty isolating converter according to claim 18 in which the multi-phase converter comprises three arms, each arm comprising a first and second bi-directional switching assembly connected in series between the ends of the transformer winding, the three arms being connected in parallel, and whereby a respective phase of the AC multiple phase output voltage is obtained by taking a centre tap from between the first and second bi-directional switching assemblies in a respective arm.

20. A heavy duty isolating converter according to claim 19 in which each switching assembly comprises a pair of transistors or other semiconductor devices (FETS, IGBTS, IGFET'S) connected in reverse, i.e, collector to collector or emitter to emitter.

21. A heavy duty isolating connector according to claim 19 or claim 20 in which each pair of switching assemblies is adapted to allow current to flow in one direction only through the arm when one device of the pair is on

whilst the corresponding device is off, and allow current to flow in the opposite direction only through the arm when the state of the two devices is reversed.

22. A heavy duty isolating converter according to any one of claims 18 to 21 in which a second control circuit is provided which is adapted to control the operation of the switching devices in the first output subcircuit.

23. A heavy duty isolating converter according to claim 22 in which the devices are controlled using a soft switching strategy.

24. A heavy duty isolating converter according to claim 22 or claim 23 in which the control circuit is adapted to switch the switching devices in one arm so that the voltage present at the respective centre tap is modulated over time to approximate (when smoothed) a sinusoidal waveform corresponding to a desired ac waveform.

25. A heavy duty isolating converter according to any one of claims 14 to 24 in which the second subcircuit comprises at least four switching devices connected in a bridge, switching of the devices being adapted to rectify the sinusoidal waveform in the associated secondary winding to produce a substantially single polarity output.

26. A heavy duty isolating converter according to claim 25 in which a filter circuit is provided to smooth the rectified output of the DC output stage.

27. A heavy duty isolating converter according to any preceding claim which is adapted to convert line voltages in the order of 450 volts nominal to 4000 volts nominal.

28. An auxiliary power supply for a carriage or vehicle comprising a converter according to any one of claims 1 to 27, input terminals for connecting the converter input to a line voltage, and output terminals across which the output from the converter may be accessed.

29. An auxiliary power supply according to claim 28 which further includes a battery adapted to store charge.

30. A carriage or vehicle including an auxiliary power supply according to claim 28 or claim 29.

31. A heavy duty isolating converter substantially as described herein with reference to Figures 1 to 6.

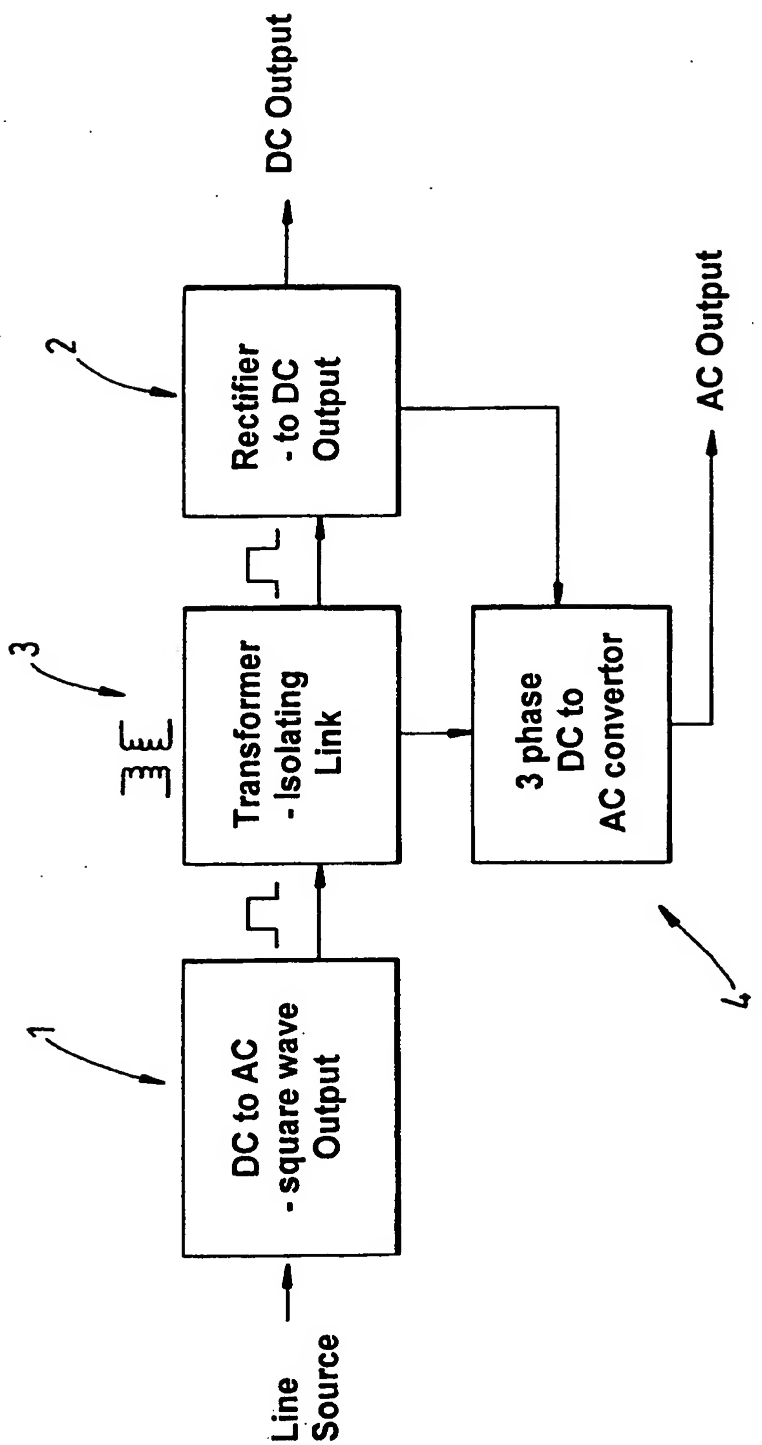


Fig. 1 (Prior Art)

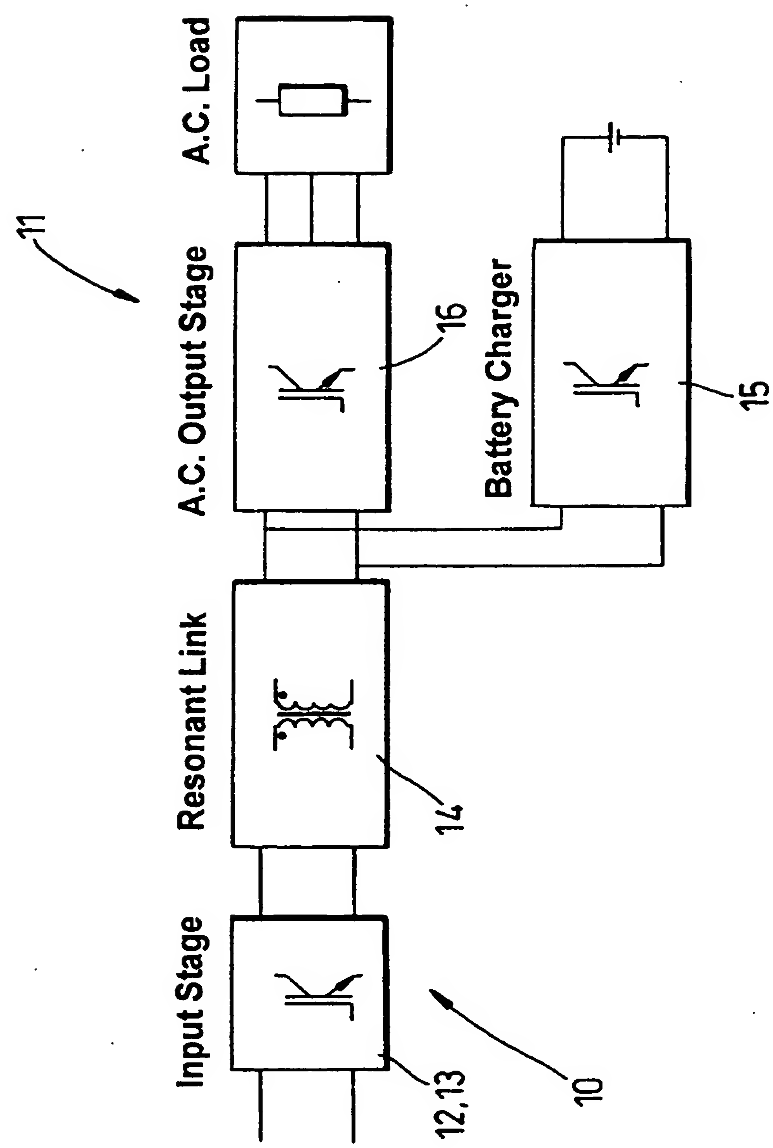

Input Stage
Resonant Link
A.C. Output Stage
A.C. Load
Battery Charger
10
11
12,13
14
15
16

Fig. 2

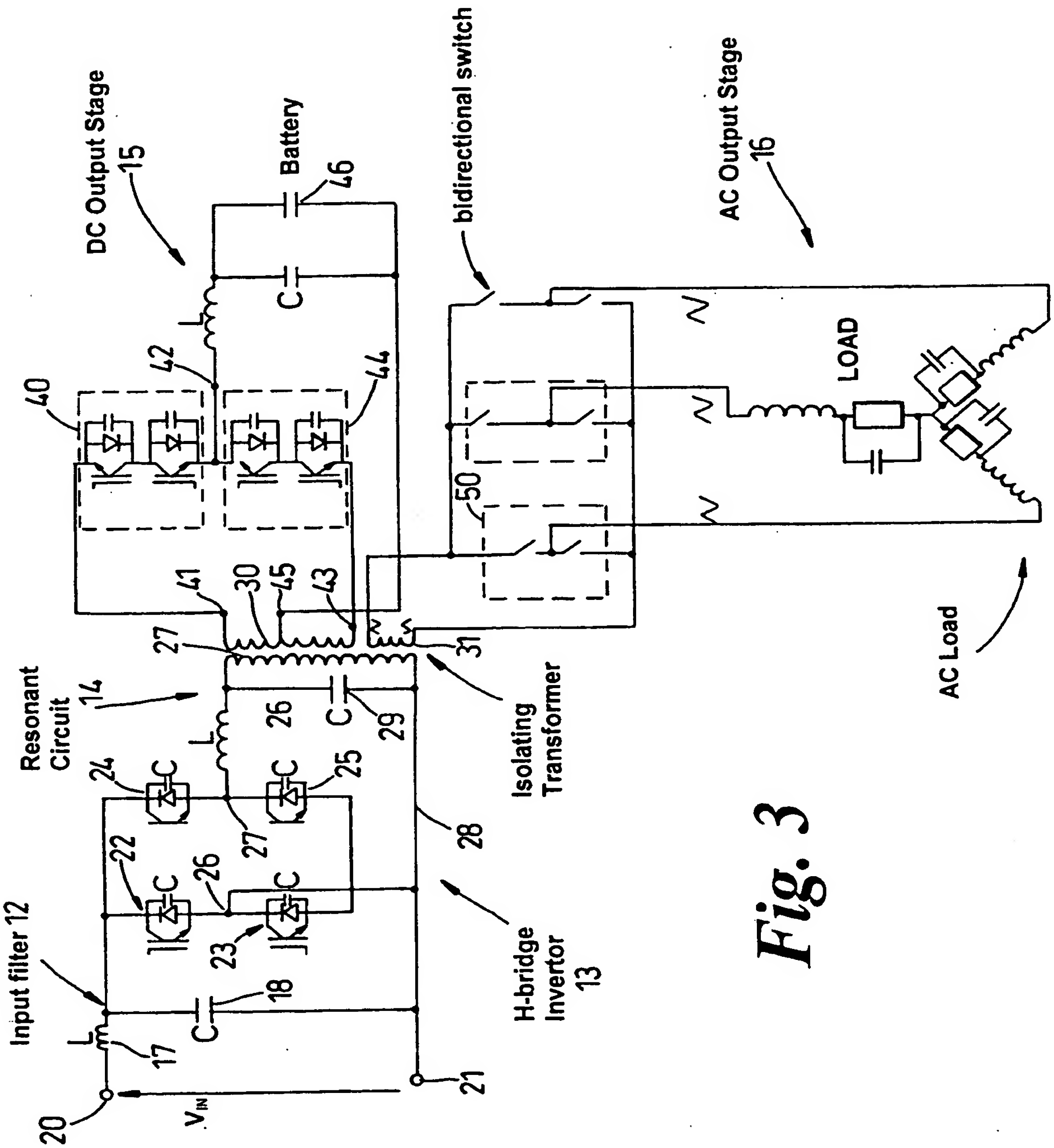

Input filter 12
H-bridge Invertor 13
Resonant Circuit 14
DC Output Stage 15
Battery
bidirectional switch
AC Output Stage 16
LOAD
AC Load
Isolating Transformer
V_{IN}

Fig. 3

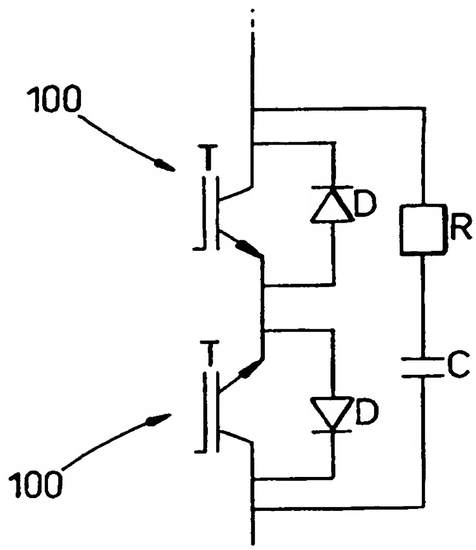


Fig. 4

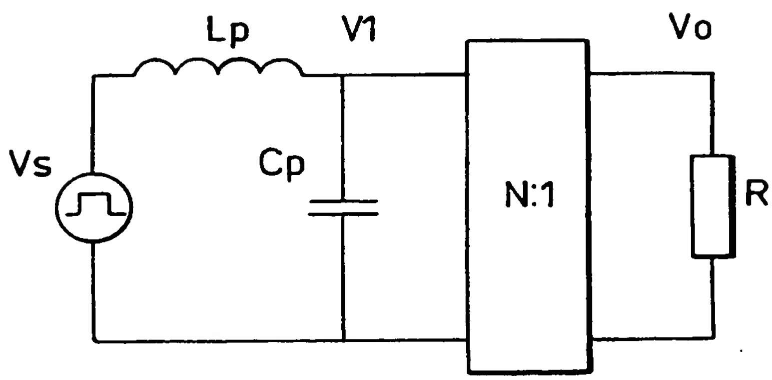
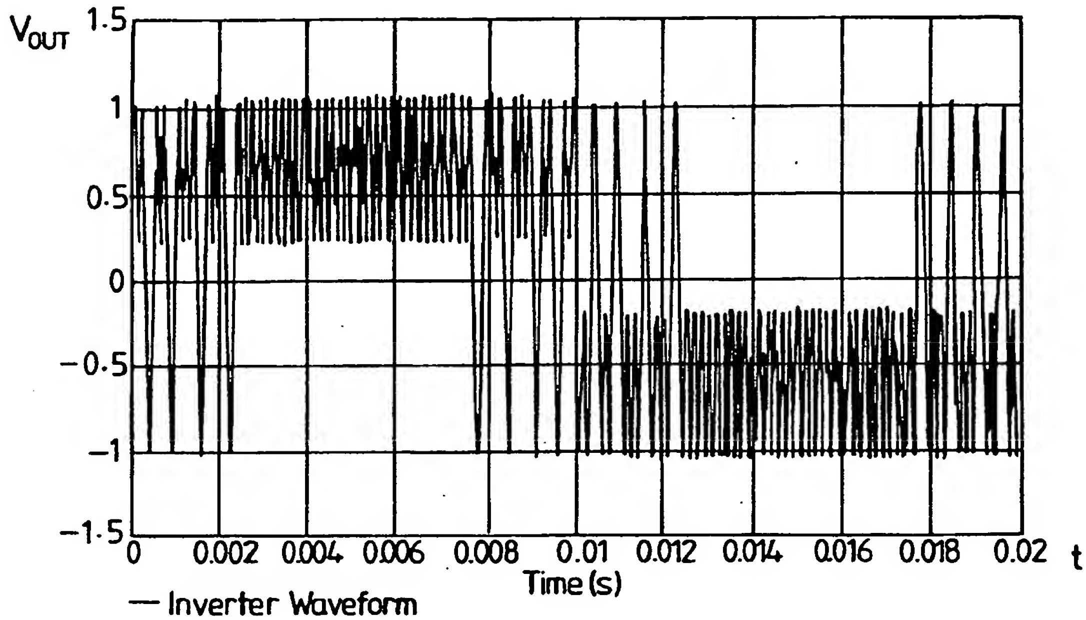
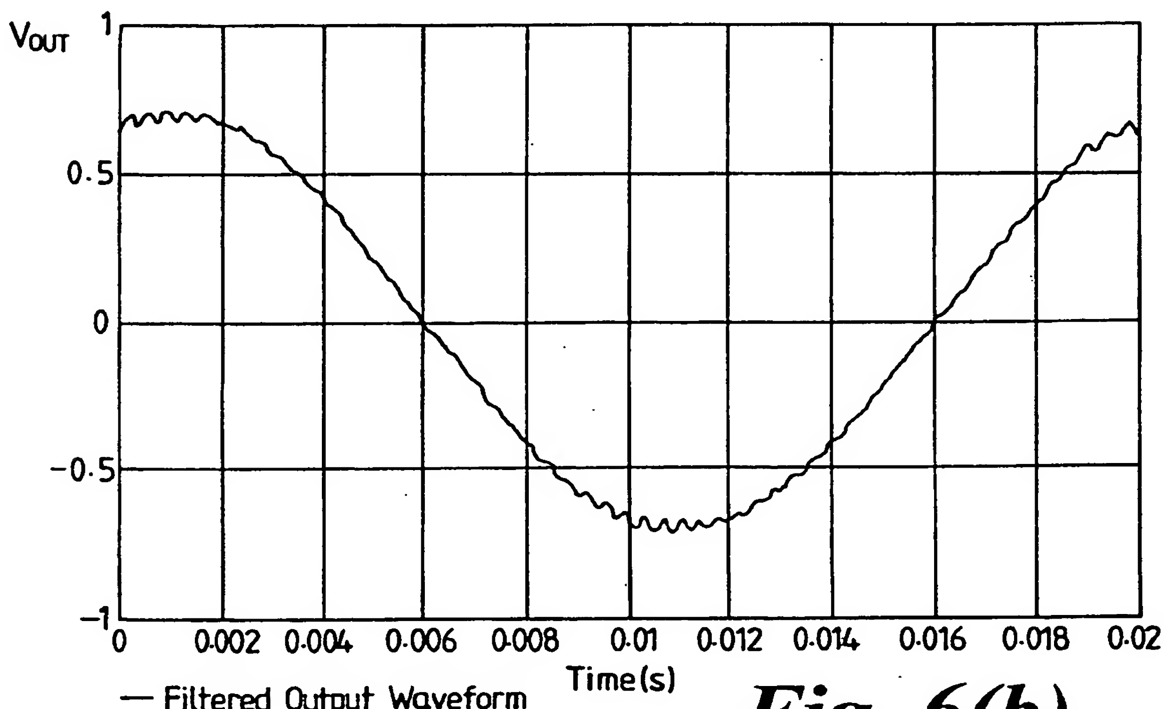


Fig. 5



VOUT
1.5
1
0.5
0
−0.5
−1
−1.5
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
t
Time (s)
— Inverter Waveform

Fig. 6(a)



VOUT
1
0.5
0
−0.5
−1
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
Time (s)
— Filtered Output Waveform

Fig. 6(b)

INTERNATIONAL SEARCH REPORT

Inter. ...nal Application No
PCT/GB 00/00365

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H02M3/335

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H02M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DATABASE INSPEC 'Online! INSTITUTE OF ELECTRICAL ENGINEERS, STEVENAGE, GB SULISTYONO W ET AL: "A series resonant AC-to-DC rectifier with high-frequency isolation" Database accession no. 5122744 XP000887281 page 784; figures 1,2 page 785, left-hand column, paragraph 3 page 788, left-hand column, last paragraph -right-hand column, last paragraph; figure 9D page 789, left-hand column, paragraph 2 page 789, left-hand column, last paragraph	1,4-6,8, 12
A	& IEEE TRANSACTIONS ON POWER ELECTRONICS, NOV. 1995, USA, vol. 10, no. 6, pages 784-790, ISSN: 0885-8993	10
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 May 2000	19/05/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Roider, A

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Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 208 738 A (JAIN PRAVEEN K) 4 May 1993 (1993-05-04) column 2, line 12 - line 21 column 3, line 37 - line 42; figures 1-3	1,5,6,8, 9
Y	US 5 638 260 A (BEES GEORGE L) 10 June 1997 (1997-06-10) column 3, line 43 - line 46	1,5,6,8, 9
A	US 5 559 685 A (LAUW HIAN K ET AL) 24 September 1996 (1996-09-24) column 1, line 16 - line 20 column 2, line 62 - line 65 column 4, line 34 - line 39 column 4, line 56 - line 60 column 4, line 63 - line 67 column 7, paragraph 4 column 11, paragraph 2 figures 7,8	2,3,7
A	US 5 668 707 A (BARRETT ALFRED HENRY) 16 September 1997 (1997-09-16) column 2, line 47 - line 65 column 3, line 23 - line 45 column 3, line 63 -column 4, line 1 column 4, line 6 - line 8	10

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte .onal Application No
PCT/GB 00/00365

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		EP 0786166 A	30-07-1997
		JP 10511836 T	10-11-1998
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US 5668707 A	16-09-1997	NONE	